

# **Reverberation Modeling and Data Analysis in ASIAEX**

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## **LONG-TERM GOALS**

Shallow water acoustics and the performance of sonar systems in littoral environments are critical areas of interest to the US Navy. In response to this, the Office of Naval Research sponsored a series of acoustics experiments in the East and South China Seas, hereafter referred to as ASIAEx. One of the components of these experiments was a study of shallow water reverberation. The long-term goals of this study are to provide a better understanding of shallow water reverberation, its statistics, and the primary mechanisms that define its structure. By improving our understanding, the influence of reverberation on active systems may be reduced through smarter data processing.

## **OBJECTIVES**

The objective of this research was to continue the development of a model capable of computing the influence of propagation on both interface and volume reverberation from a broadband pulse. Spatial correlations and statistics of the predicted reverberant signal were examined. The results from further analysis will be used to compare such predictions with data collected in the recent ASIAEx experiments. By understanding the role of the acoustic propagation in such signals, a clearer description of the underlying dominant scattering mechanisms should emerge.

## **APPROACH**

The underlying acoustic model used in this work was the parabolic equation (PE) model. In order to predict reverberation levels, a formal treatment of backscatter was performed in the context of the PE approximation. Essentially, this model incorporates the Born approximation into a two-way PE model, assuming multiple forward scattering occurs due to all environmental fluctuations, but only single backscattering from each scattering patch. Both interface roughness and volume sound speed and density inhomogeneities were treated. It furthermore assumed a constant scattering strength could be used to characterize an entire scattering patch, thereby neglecting much of the details of the specific scattering mechanisms and dominating the result by the total field predicted at the scattering patch. Thus, the statistics and general structure of the predicted reverberation return were solely a function of the propagation. Previous applications of a similar PE reverberation model provided good agreement with reverberation data measured near the mid-Atlantic Ridge [1, 2].

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## WORK COMPLETED

The theoretical development of the PE reverberation model was completed in FY00 and the inclusion of density fluctuations in the sediment volume was added in FY01.

Both interface roughness and sediment sound speed/density fluctuations were computed based on characteristic spectral models of such perturbations. These were incorporated into the PE model, and solutions of the acoustic propagation for both CW and broadband pulse sources were generated. During this development portion, only a single realization for both the interface and volume fluctuations was used in order to concentrate on the processing algorithms. The rms fluctuation of the interface was set to 1m while the volume sound speed rms fluctuation was fixed at 15m/s. Both types of perturbations were included in all calculations, although the reverberation due to each was considered separately. Thus, it is possible that one type of perturbation may dominate the structure of both types of reverberation.

From both CW and broadband calculations, vertical spatial correlations of the reverberation field were computed. Additionally, the statistical characteristics of the reverberation signal were examined. Such results from future calculations will eventually be compared with measured data to determine the influence of propagation and, hopefully, help discriminate specific scattering mechanisms.

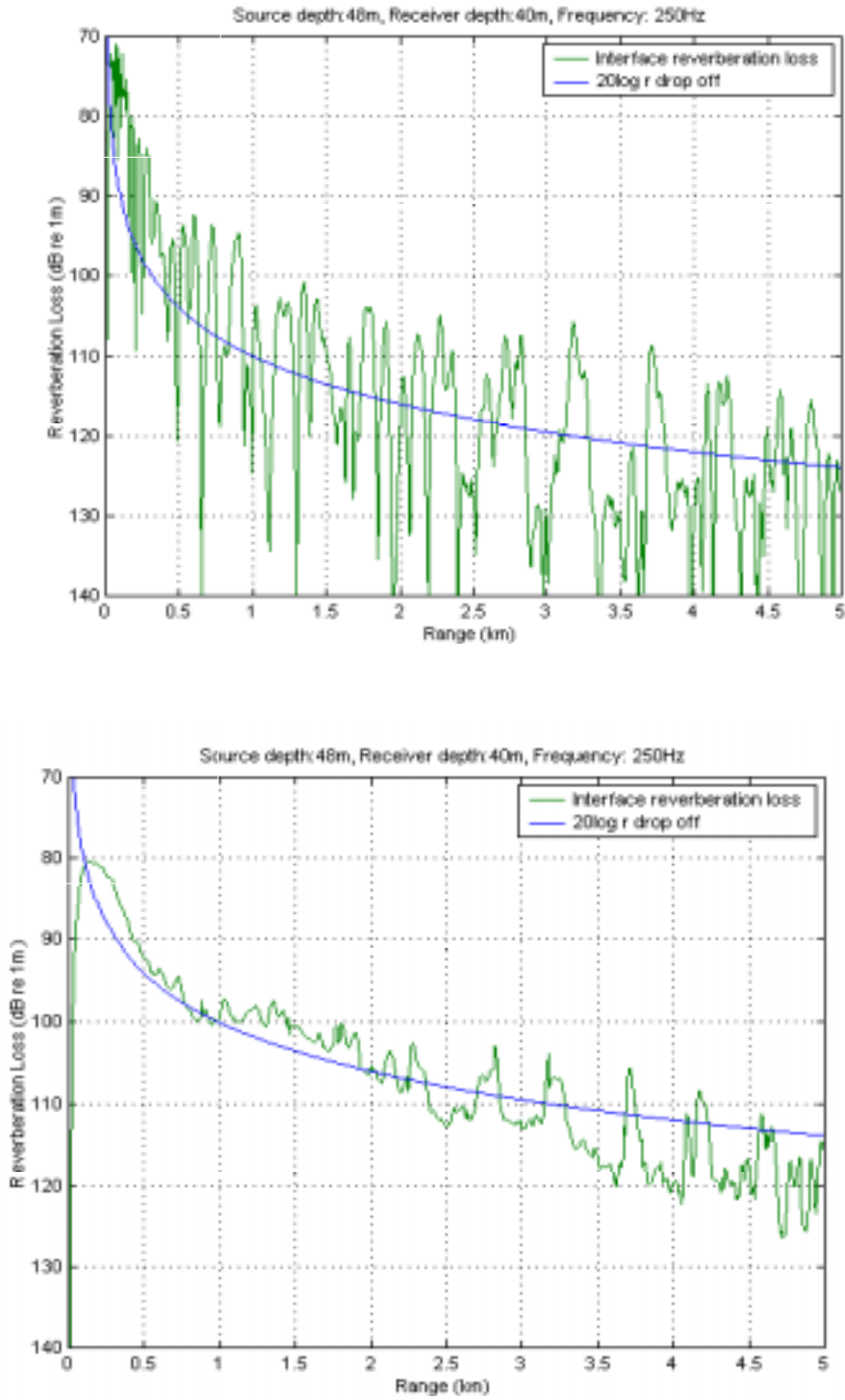
## RESULTS

The technique for computing the structure of both CW and broadband reverberation signals was described in the FY00 effort [3]. In FY01, this analysis was extended to include the spectral characteristics of the predicted reverberation structures.

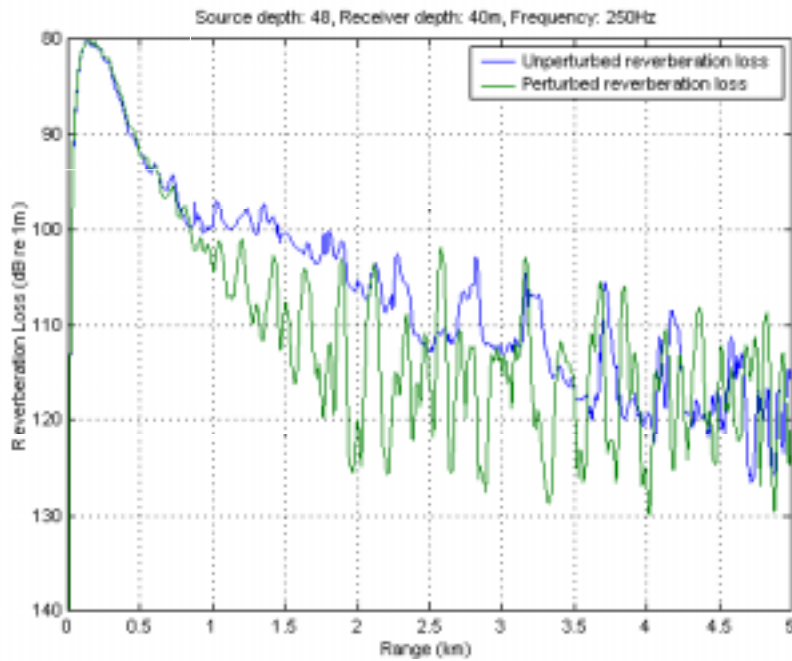
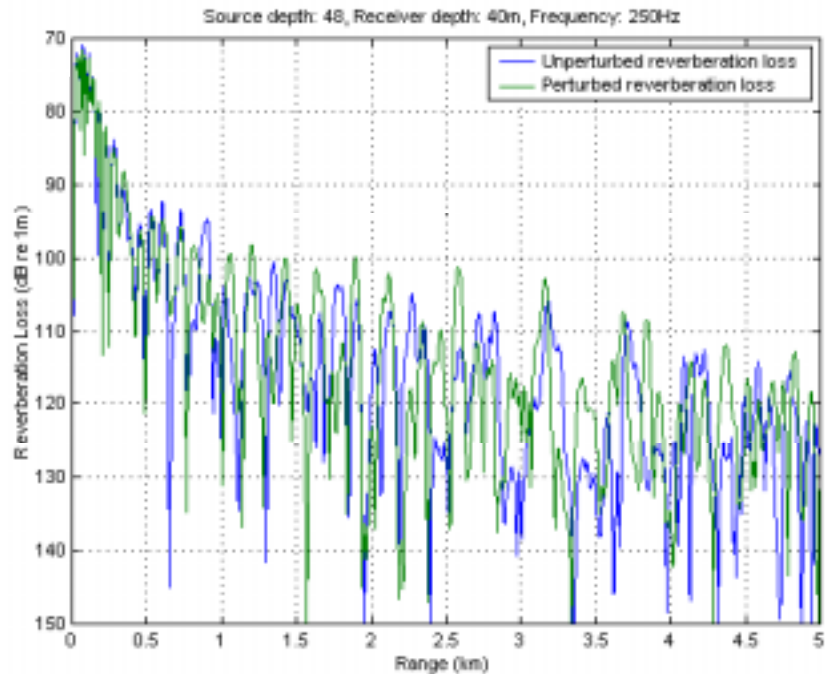
The structure of the predicted reverberation for a CW signal of 250 Hz from the bottom interface and sediment volume are displayed in Fig. 1. In addition, a curve displaying the cylindrical spreading factor is included. To obtain more direct information about the effect of the perturbations on the two-way propagation, the same calculations were performed without interface or sediment sound speed fluctuations. These results are compared in Fig. 2. The difference between these TL curves with and without the perturbations (corresponding to a ratio of intensities) is presented in Fig. 3.

Two approaches were then used to examine the statistical character of the predicted reverberation structures. They are:

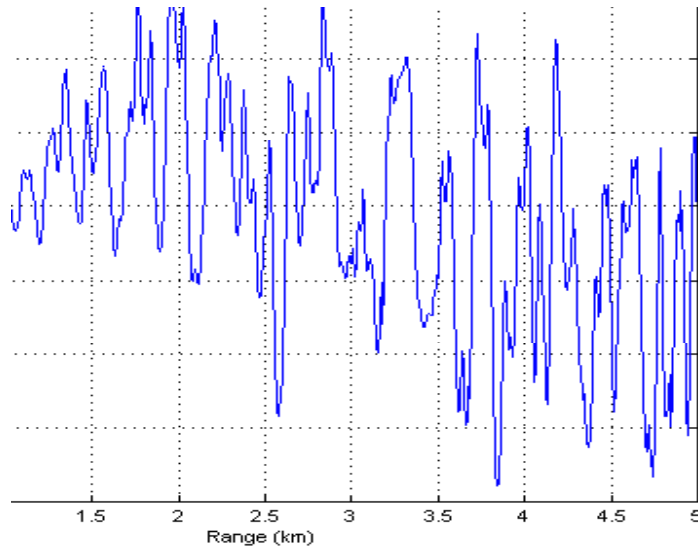
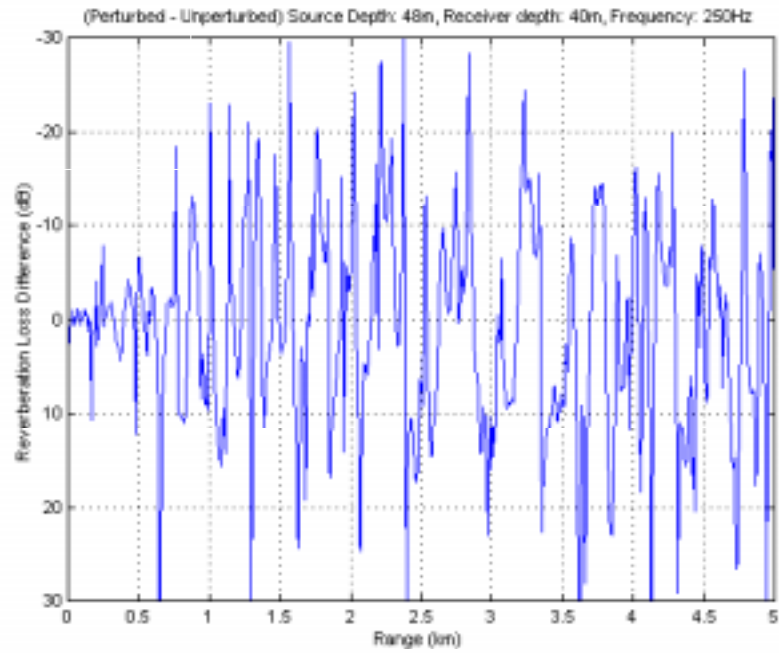
- Signal Analysis 1: Power Spectral Density – DFT of the magnitude squared range-reduced reverberation (i.e.,  $r^2 \times |p_{rev}|^2$ ).
- Signal Analysis 2: Power Ratio Spectral Density – DFT of the magnitude squared of the ratio of the reverberation (perturbed divided by unperturbed), i.e.,  $\frac{|p_{rev, perturbed}|^2}{|p_{rev, unperturbed}|^2}$ .



**Figure 1: Interface (left) and volume (right) reverberation loss (green curves) for two-way transmission with perturbation. Cylindrical spreading (blue curve) is also illustrated in each figure. Data are normalized to two-way transmission loss.**

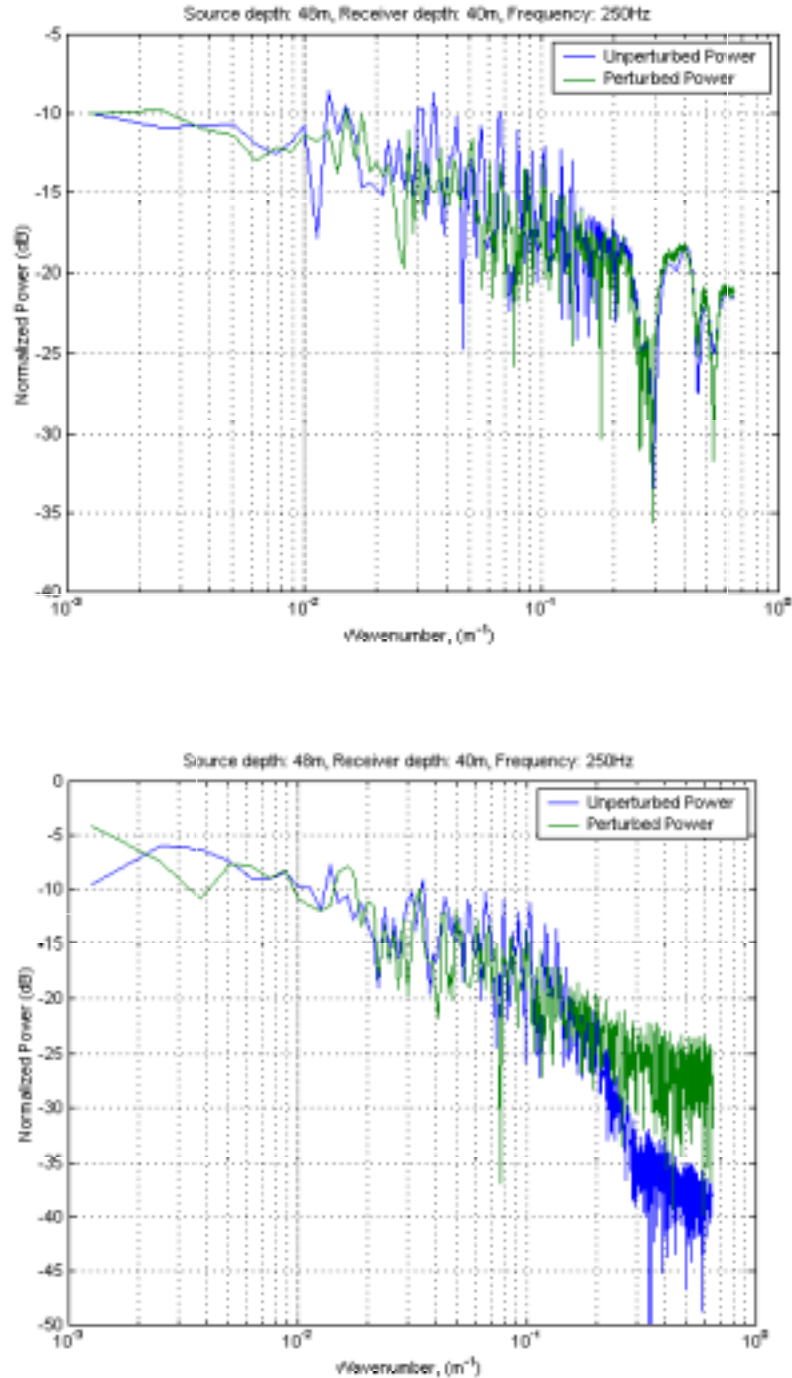


**Figure 2: Same data as Fig. 1 but now comparing two-way transmission data with perturbations (blue curves) and without perturbations (green curves) to the interface and sediment volume sound speed.**

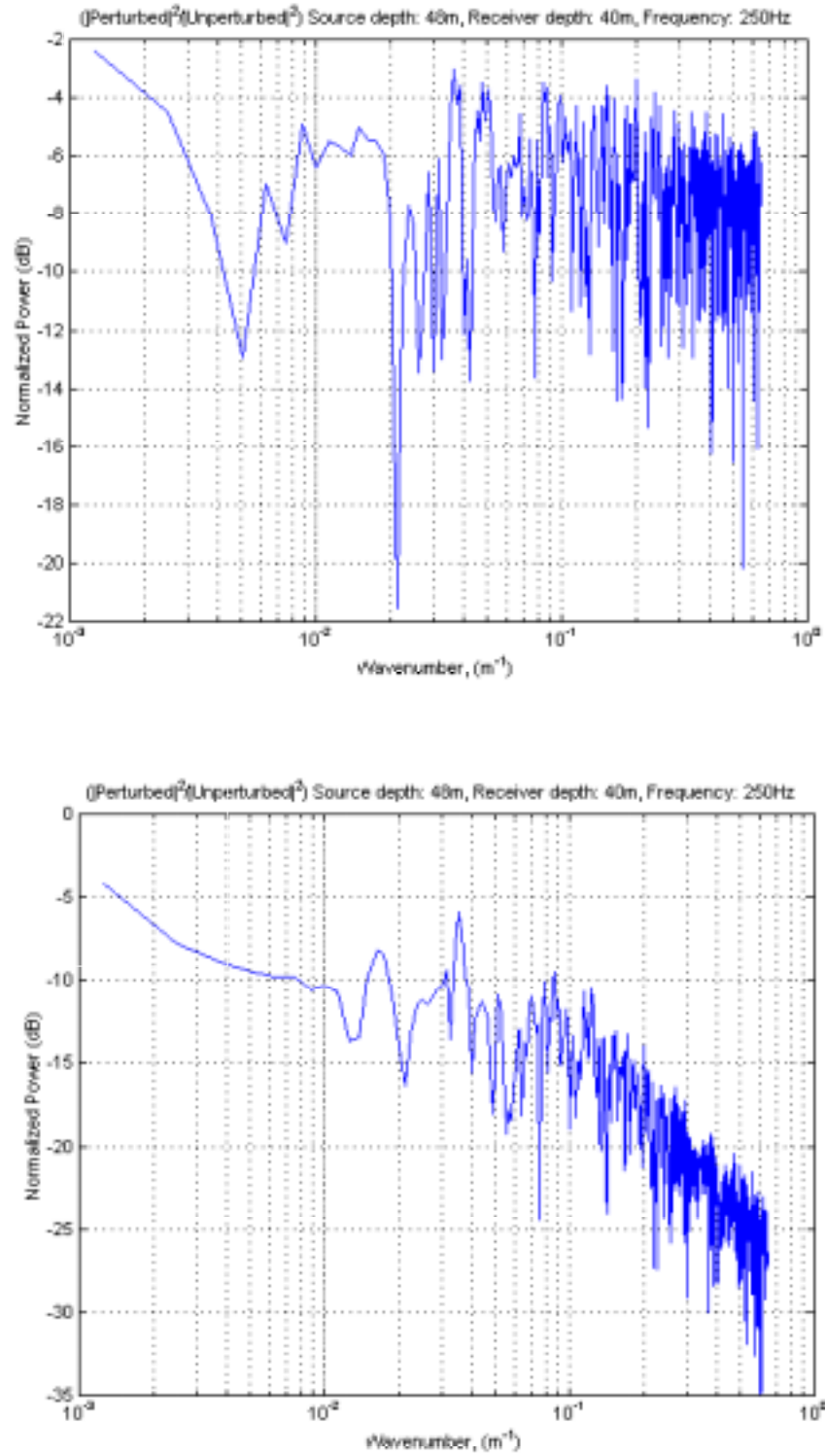


*Figure 3: Differences between data presented in Fig. 2 (intensity ratios).*

The results of these analyses are provided in Figs. 4 and 5. In Fig. 4, both the perturbed and unperturbed two-way propagation signals are examined after removing the influence of cylindrical spreading. Figure 5 displays the spectral character of the signal difference between perturbed and unperturbed.



**Figure 4: Power spectral curves of range-reduced (cylindrical spreading removed) two-way propagation. The graphic on the left presents the data for the interface (perturbed environment – blue; unperturbed environment – green) and the graphic on the right presents the data for the sediment volume.**



**Figure 5: Power spectral curves of intensity ratios (perturbed/unperturbed) of two-way propagation for the interface (left) and sediment volume (right).**



The results of this analysis are, as yet, inconclusive. Further analysis is on-going in an attempt to extract a specific connection between the statistical nature of these signals and the underlying perturbations. Preliminary analysis of broadband signals has also been inconclusive, but it is hoped that such analysis will be able to separate some of the multipath effects and isolate discrete regions of the environment.

## **IMPACT/APPLICATIONS**

The extraction of statistical information from the reverberation signal that can be related to the statistical character of the perturbations would suggest that future systems might be able to improve performance by accounting for predictable features in the reverberation.

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3. K.B. Smith and L.-S. Li, "Broadband Parabolic Equation Modeling of Acoustic Bottom Interface and Volume Reverberation in Shallow Water," Proceedings of 5th European Conference on Underwater Acoustics, Lyon, France, 10-13 July, pp. 1171-1176 (2000).

## **PUBLICATIONS**

K.B. Smith, L.-S. Li, B.-C. Lee, and H. Kao, "Sediment interface and volume reverberation modeling with the parabolic approximation," J. Acoust. Soc. Am. (Invited abstract for 142<sup>nd</sup> Meeting of the Acoust. Soc. Am., 3-7 Dec 2001, Ft. Lauderdale, FL).

Lit Siew Li, "Sediment Volume Reverberation Modeling Using Parabolic Equation Methods," M.S. Engineering Acoustics, Master's Thesis, Naval Postgraduate School, September, 2000.